Seismicity Induced by Petroleum and Geothermal Activities

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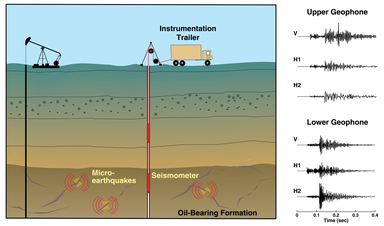


Introduction

Microseismic fracture mapping at Los Alamos started with the Hot Dry Rock geothermal project. The fractured reservoir volumes created and stimulated during massive hydraulic fracturing were imaged using the microearthquakes induced by injection. Seismic receivers need to be placed downhole at or near reservoir depth to detect the small magnitude events. In the 1990s we began to apply these techniques to oil and gas problems. In addition to the now well-known application of hydraulic fracture imaging, other applications include mapping natural, conductive fractures affected by extraction and pressure recovery operations, as well as monitoring and characterizing reservoir and overburden deformation induced by production.

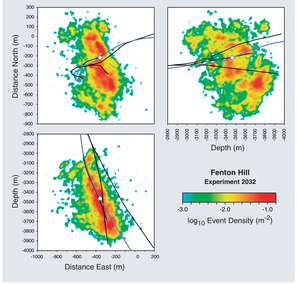
Applications

Hydraulic fracture imaging

Natural fracture imaging
- production induced
- water-flood or CO_2-flood front mapping

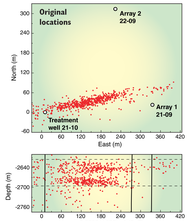
Monitoring waste containment and flow paths
- hydraulic fracture injection disposal
- CO_2 geologic sequestration
- thermal induced stress changes

Monitoring and characterizing reservoir deformation and subsidence

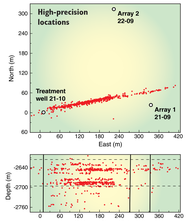


HYDRAULIC FRACTURE IMAGING

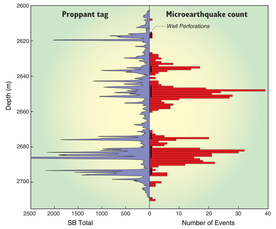
Carthage Gas Field, East Texas



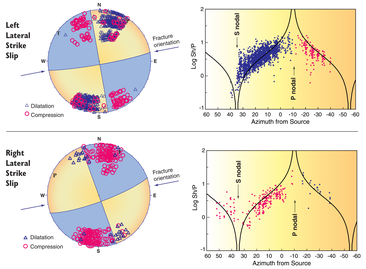
Locations of microearthquakes induced during a hydraulic fracture stimulation treatment in a tight-gas sand reservoir. The dashed lines mark the perforated interval.



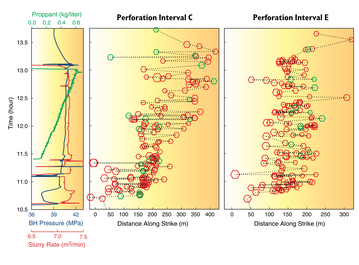
Refined images after obtaining higher-precision arrival time data via waveform correlation.



Horizontal bands of seismicity correlate closely with the treatment interval perforation schedule and proppant placement.

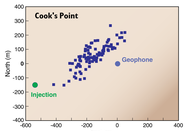


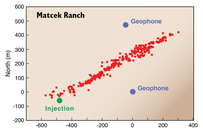
Re-picking the data in a spatial sequence revealed a remarkable similarity of adjacent-source waveforms and evolution of waveforms along the treatment length. Systematic polarity changes and phase amplitude ratios indicate uniformity of focal mechanisms along the entire fracture.



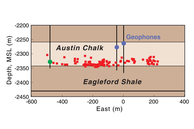
The fracture growth is characterized by systematic space-time patterns of seismicity along the treatment length.

Austin Chalk, Texas

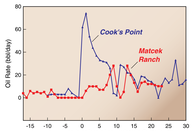




Two stimulation treatments were mapped in the Giddings Austin Chalk field. Event locations at Cook's Point show greater width development and less length than the Matcek Ranch stimulation.



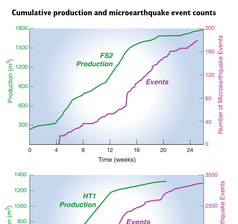
Reflected phase off the base of the Eagleford allowed location depths to be constrained.



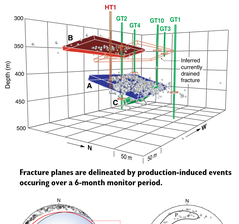
The wider stimulation zone imaged at Cook's Point is correlated with a greater production response.

PRODUCTIVE FRACTURE IMAGING

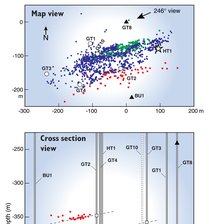
Clinton County, Kentucky



Event rate changes correlate with production rate changes. Seismic response lags production by 2–3 weeks.



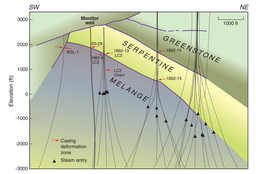
Composite fault plane solutions indicate thrust displacement along the mapped, low-angle fractures. Induced stress changes are very small (<0.1 MPa).



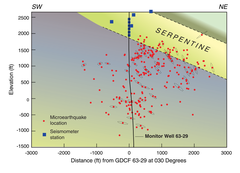
Seismically active fractures correlate with previously depleted zones; current productive zone is aseismic.

WELL-BORE DEFORMATION

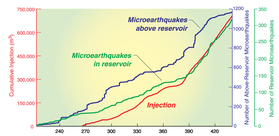
The Geysers, California



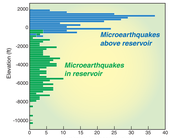
Above-reservoir casing deformations have been observed in several wells in the southeast Geysers field. Deformation is concentrated over short depth intervals at the upper and lower contacts of a serpentine unit.



Small magnitude events were detected above the reservoir by placing a downhole receiver array within the upper 800 feet of an abandoned well. Event occurence terminates near the base of the serpentine unit.



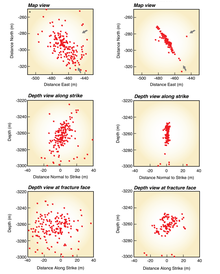
Both the above-reservoir and the deeper reservoir seismicity show correlations with reservoir injection activity in the study area.



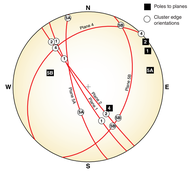
INDUCED SEISMICITY

In-Situ Laboratories for Understanding Fluid-Driven Fracture Systems

Microearthquakes induced by fluid injection provide a means to study fluid migration, fracture creation and faulting, with an optimal combination of resolution and subsurface coverage. Supplemental information often available with induced experiments includes borehole imagery, stress measurements and fluid pressure and flow data, information that greatly aids in understanding similar earth phenomena where little independent information exists. Further, the nature of induced microseismicity enables exceedingly high-precision locations to be obtained, revealing discrete fracture networks and fine-scale rupture sequence patterns with remarkable clarity.

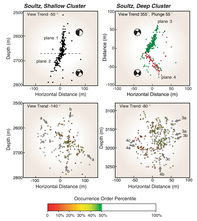


A sub-cluster of events from the Fenton Hill HDR reservoir. Original locations (left) and refined locations (right) after obtaining high-precision arrival-time data. In the face-on view (bottom right) sharp, straight edges bound the location pattern.



Discrete fracture plane orientations imaged from the Fenton Hill reservoir. The distinct fracture edges resolved correlate with significant fracture-plane intersections.

Location of the Soultz HDR site.



Two event sub-clusters each delineating the intersection of two planes. Looking along line of intersection (top) and face-on views (bottom). Linear trends can be seen along fracture faces (bottom). The event sequences indicate early fluid invasion along linear trends.